Neutron Capture on Unstable Nuclides

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The abundance of isotopes produced in nuclear explosions and asymptotic-giant-branch stars are affected by neutron capture on unstable nuclides (radioactive isotopes). The thermonuclear neutron fluences produced in nuclear detonations in past underground-nuclear-weapons tests were determined by placing radiochemical (radchem) detectors in components of the device and measuring the radioactive isotopes produced in the post-shot debris. The neutron capture in the 1- to 30-keV energy range affects the isotopic distribution of these elements. The Detector for Advanced Neutron Capture Experiments (DANCE) on flight path (FP) 14 at the Lujan Neutron Scattering Center (Lujan Center) is designed to measure neutron-capture cross sections with neutron energies from thermal (0.0253 eV) to 100 keV on radioactive targets with masses as low as 0.5 mg. Because DANCE discriminates backgrounds on the basis of γ-ray multiplicity (the number of γ-rays emitted in the decay of a compound nucleus) and neutron-binding energy (which determines the total energy of the γ-rays emitted in the cascade), it provides superior performance over other γ-ray detectors like deuterated-benzene scintillators. During the 2002 run cycle at Los Alamos Neutron Science Center (LANSCE), we made the first measurement of the neutron-capture cross section of ^{234}U with DANCE.

Measuring Neutron Capture on Unstable Nuclides with DANCE

Neutron-capture cross sections are measured with DANCE using the neutron time-of-flight (TOF) method. A neutron-capture event is registered when γ-rays are detected in the DANCE scintillator array. The neutron energy is determined by TOF (the time that γ-rays are emitted from the target relative to the time protons from the Proton Storage Ring strike the tungsten target producing a burst of neutrons used in experiments). The neutrons emitted from the tungsten target are slowed down in a water moderator to give an intense epithermal (> ~ 0.5 eV) neutron flux. These moderated neutrons travel along a 20.3-m vacuum pipe lined with neutron collimators to produce a well-defined 0.89-cm-diam neutron beam at the center of DANCE. DANCE consists of 159 barium-fluoride scintillators in a soccer-ball configuration. Barium fluoride has a high efficiency for detecting γ-rays with energies above 1 MeV. The thickness of the barium-fluoride shell is 15 cm. Barium fluoride has a relatively low sensitivity to neutrons scattered from the target. A 6-cm-thick ^{6}LiH absor-ber surrounding the target position further reduces the sensitivity of the array to scattered neutrons. Fig. 1 illustrates a cascade of γ-rays following neutron capture by a target nucleus. A γ-ray cascade can have large γ-ray multiplicities. The sum of the energies of γ-rays that are detected within a time window of several nanoseconds is equal to the neutron-binding energy of the compound nucleus. Summed γ-ray energies following neutron capture in barium fluoride have different neutron-binding energies from the natural isotopes of barium. The summed γ-ray energies from barium are different from the target and can be discriminated against.

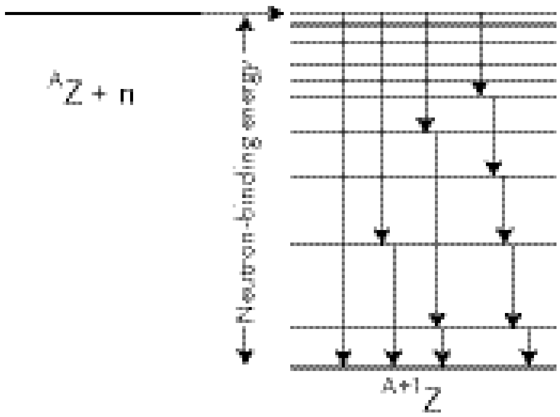

Fig. 1. A target nucleus with atomic number Z and mass A captures a neutron to form an excited state in the compound nucleus, ^{A+1}Z. The γ-ray decay of this compound nucleus can proceed with different γ-ray multiplicities. This illustration has a reduced level density for visual clarity. A 4-π detector will sum the γ-rays to yield the neutron-binding energy, which is characteristic of the compound nucleus.

A target consisting of 1 mg of ^{234}U electro-deposited on two 2.5-μm-thick titanium foils was bombarded in the DANCE target chamber. The only previous ^{234}U neutron-cross-section measurements made in the 1-eV to 100-keV energy range were total cross sections (i.e., capture plus scattering) and preliminary neutron-capture measurements using deuterated-benzene scintillators at FP14 with 10-mg samples. In these FP14 measurements, the neutron resonances were broadened by neutron scattering in the quartz vials used to hold the ^{234}U oxide.

The advantage of using a 4-π detector is illustrated in Fig. 2, which shows the neutron-capture rate in ^{234}U at neutron energies near the 5.16-eV resonance. The first curve shows the neutron-capture rate obtained when a window was set for summed γ-ray energies around the 5.29-MeV sum peak corresponding to the neutron-binding energy in the ^{234}U compound nucleus. The second curve shows the neutron-capture rate after subtracting captures in the barium-fluoride crystals. After subtraction, the off-resonance background is reduced by more than 2 orders of magnitude.

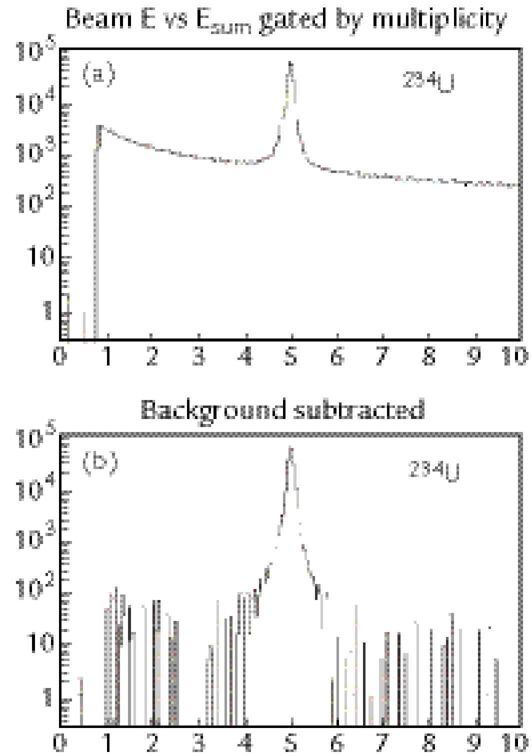

Fig. 2. Neutron-capture rates near the 5.16-eV resonance of ^{234}U before (a) and after (b) subtraction of γ-rays from neutron capture in the barium-fluoride scintillators.

Conclusion

The γ-ray-detection efficiency of DANCE enabled us to measure neutron-capture cross sections on 1-mg targets with good statistics. Most unstable nuclides require this level of detection efficiency. The 4-π geometry of the DANCE array allows the measurement of the total γ-ray energy emitted per neutron capture. This geometry greatly reduces the background caused by neutrons scattered from the target into the barium-fluoride array. As such, DANCE allows for the measurement of neutron capture on many isotopes of importance to both nuclear astrophysics and the interpretation of radchem weapons diagnostics. With the intense neutron flux available at Lujan Center, DANCE is presently the most sensitive instrument for neutron-capture experiments.

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